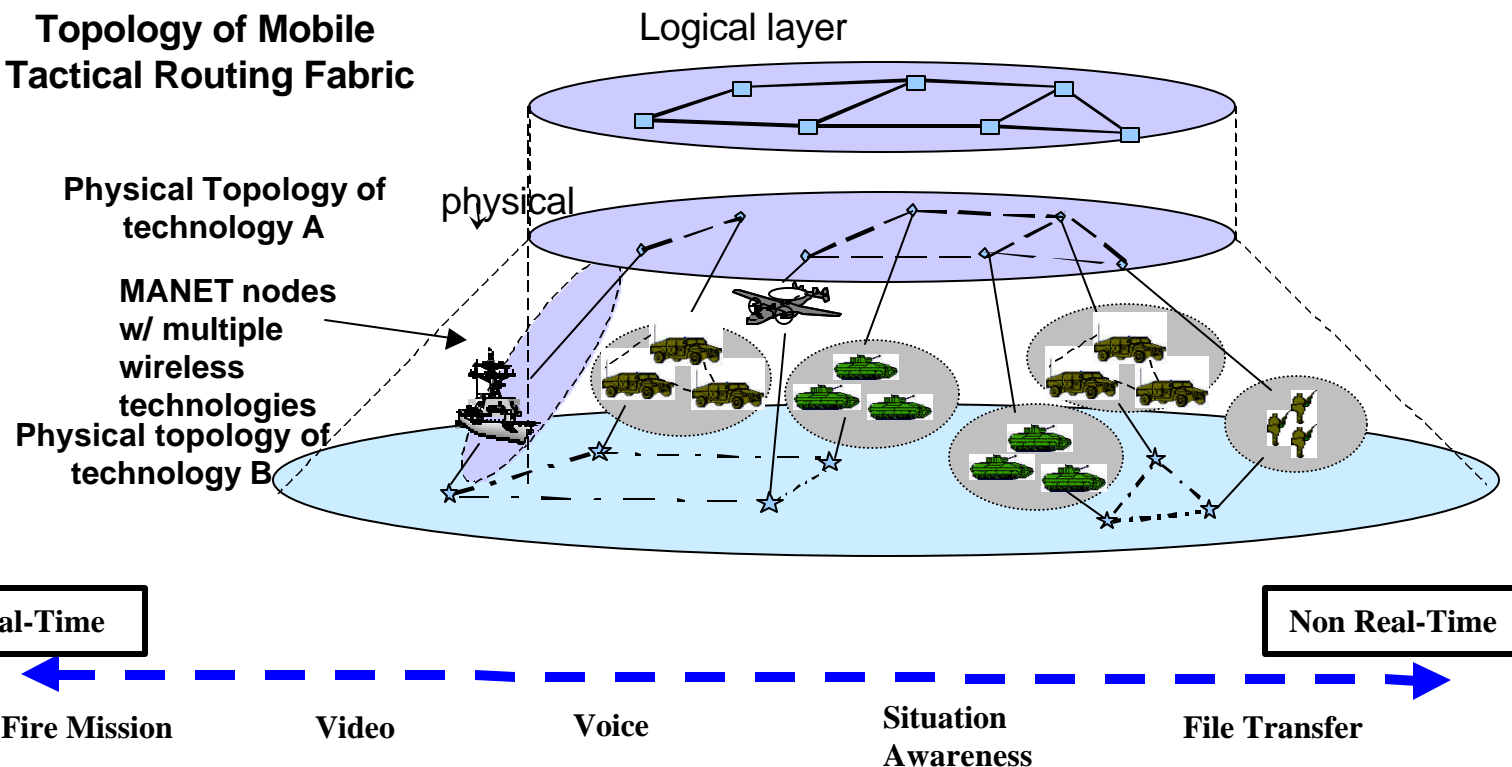# Antenna Applications
of
Meta Materials

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September 2000

Topology of Mobile Tactical Routing Fabric

Logical layer

Physical Topology of technology A

physical

MANET nodes w/ multiple wireless technologies

Physical topology of technology B

| Real-Time | | Non Real-Time |

Fire Mission　　　Video　　　Voice　　　Situation Awareness　　　File Transfer

- **Technology**
  - **Merging Real-Time and Non-Real Time on single mobile wireless network**
  - **Combination of ad-hoc and mobile backbone communication service**
  - **Topology control and predictive routing for mobile LOS backbones**
  - **Optimization of LOS and non-LOS links on multiple spatial sides**
  - **Tactical picture-based bandwidth allocation for real-time traffic**
  - **Modeling and simulation with realistic fidelity and scale**

2
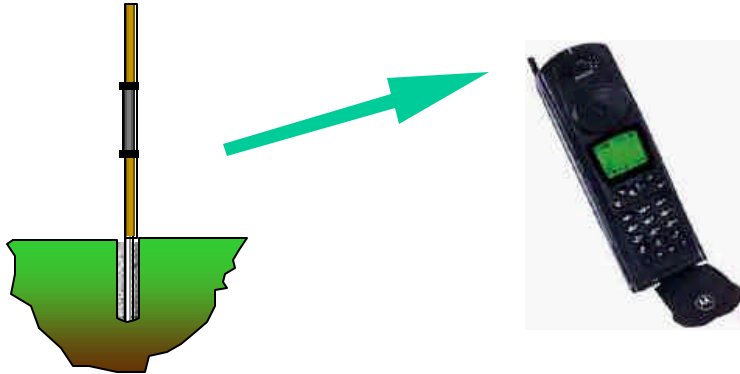
- ■ **Physically Small, Electrically Large Antennas (λ / 10 ® λ / 100)**
  - ◗ Fewer Constraints for Wireless Communications
  - ◗ Compact DF for Geolocation
  - ◗ Integrated RF Filtering

- ■ **Low Profile, High Performance Integrated RF Front End**
  - ◗ Integrate Antenna with Front End
 - ◗ Complement / Extend Software Radios
 - ◗ Cover 2 MHz To 2 GHz Bands

- ATO addressing broadband communications for mobile users
  - Programs such as ACN, SUO, FCS
  - Need is for flexible wideband RF links
- Antennas needed:
  - Must match receiver designs such as Ultracom
  - Cover the frequency range of 20 MHz to 2.5 GHz
  - Have 100s of MHz of instantaneous bandwidth for receiving
  - Have over 20 MHz bandwidth with good efficiency for transmitting

Antenna Requirement for Communications Band

Antenna Noise Factor vs. Frequency
[Lossless Antenna]
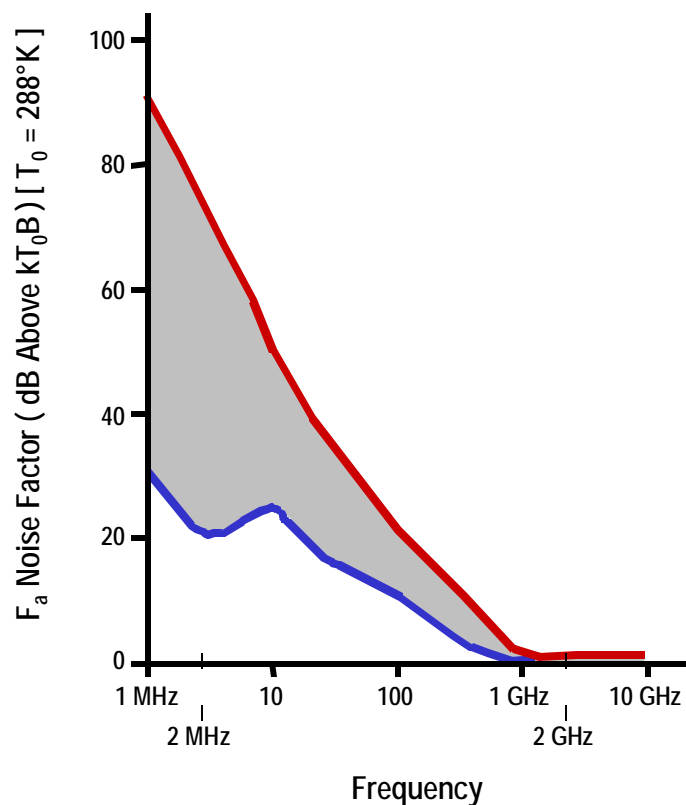
Radiation Resistance vs. Frequency
for Dipole with 2 Meter Maximum Dimension

$$20\pi^2(1/\lambda)^2$$

73.09
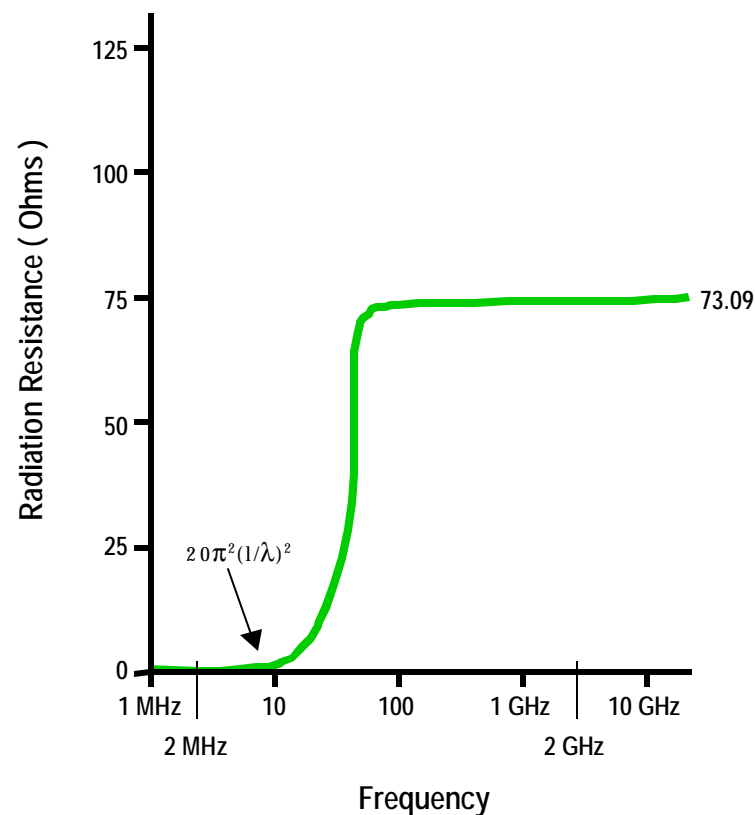
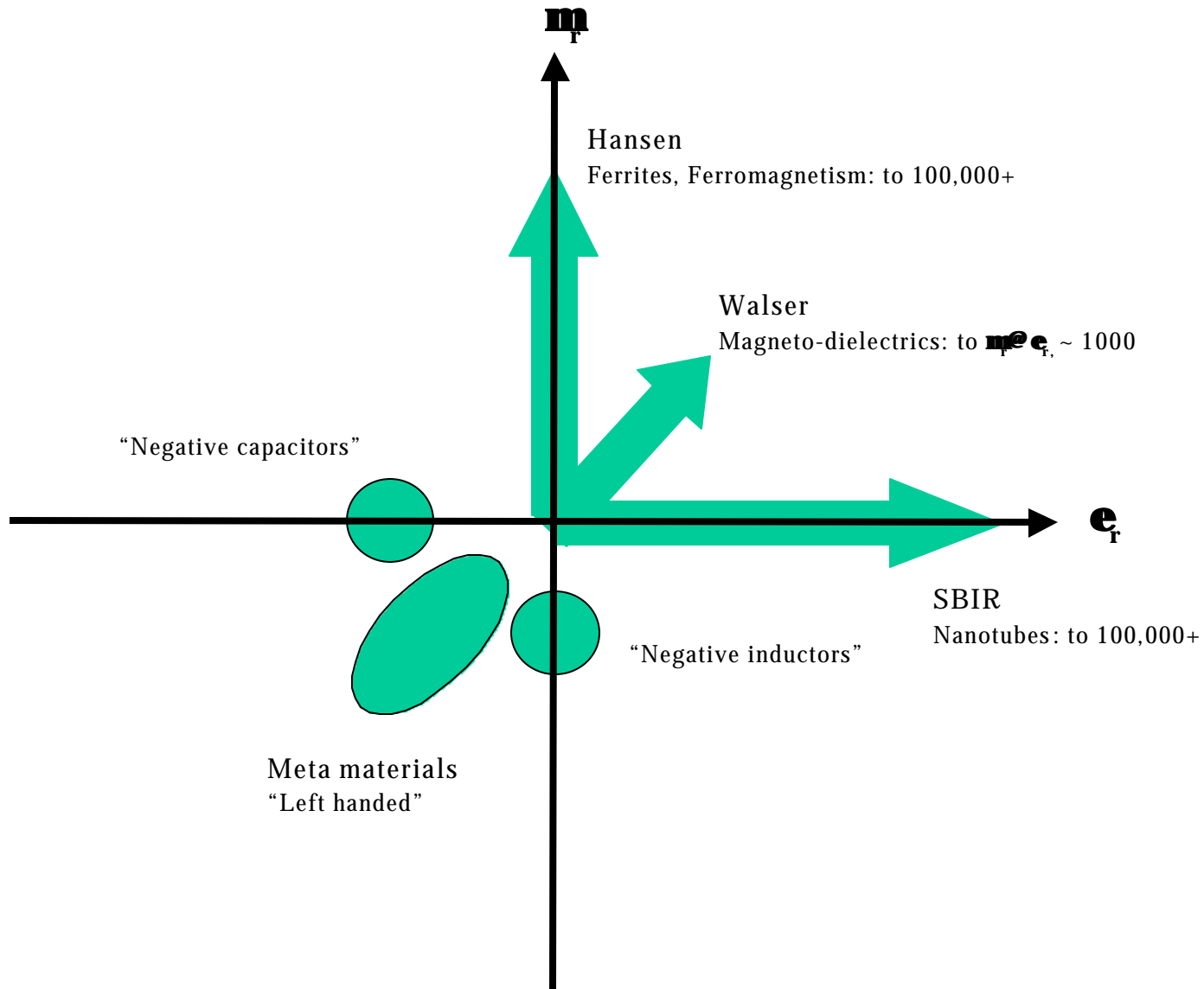**VHF and Lower Communications Demand Transmit Antenna Efficiency**

■ **Developments in Materials**

- ◗ Meta Materials
- ◗ Artificial Dielectrics and Magneto-dielectrics
- ◗ Nanotubes ($\varepsilon_r \rightarrow 100{,}000+$)

■ **Developments in Antennas and Electromagnetic Theory**

- ◗ Material Loading Concepts (Dipoles, Patches, Stripline Arrays)
- ◗ All Dielectric Antenna Concepts (Dielectric Resonators, Dielectric Waveguides)
- ◗ Numerical Electromagnetics (Material Modeling, Finite Elements, Finite Difference Time Domain, Method of Moments, Faster Computers)

Hansen
Ferrites, Ferromagnetism: to 100,000+

Walser
Magneto-dielectrics: to $\mu_r \cdot \epsilon_r \sim 1000$

"Negative capacitors"

μ_r

ϵ_r

SBIR
Nanotubes: to 100,000+

"Negative inductors"

Meta materials
"Left handed"

- "…It may be expected that magneto-dielectric materials, if low loss, would be useful in some types of antennas…there is little improvement to be realized in the arrangement of the wires in the antenna; a significant improvement will come from the use of new materials."

    - R.C.Hansen, IEEE Fellow, 18 Sep 98

- R.C Hansen's example: A patch antenna with a substrate having $\mu > 1$ and $\varepsilon \cong 1$ can have either :

    (1) a significant increase in bandwidth or

    (2) the patch can be made significantly smaller with the same bandwidth
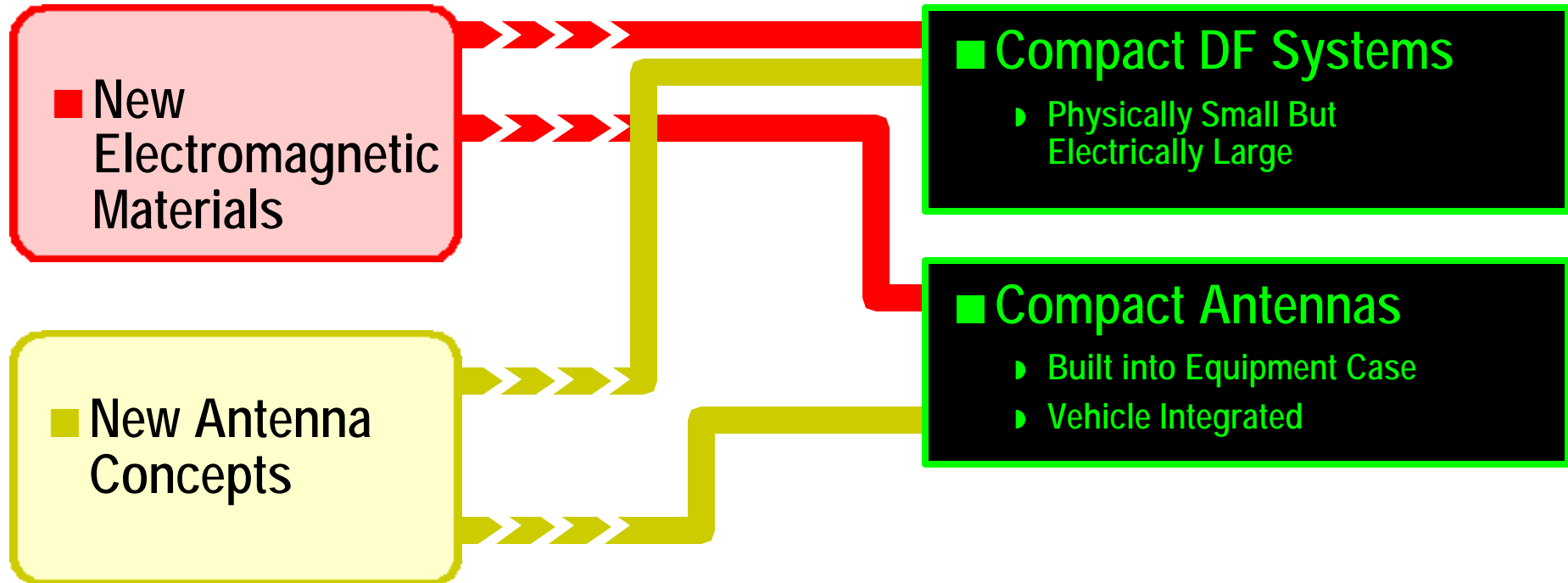
- Materials with negative constitutive parameters
  - Small antenna limitations arise from reactive fields (energy storage) in the region surrounding the antenna
  - Can materials with $-\mu$ or $-\varepsilon$ be used to reduce the reactive fields surrounding a small antenna (reducing energy storage) while not affecting or enhancing the radiation fields?

What Do New Materials Enable?

- New Electromagnetic Materials

- New Antenna Concepts

- Compact DF Systems
  - Physically Small But Electrically Large

- Compact Antennas
  - Built into Equipment Case
  - Vehicle Integrated

- Relates lowest achievable Q to the maximum dimension of an electrically small antenna, and the result is independent of how the antenna within the sphere is constructed

- Implies improving bandwidth for an electrically small antenna is only possible by fully utilizing the volume or by reducing efficiency

- Based on equivalent circuit for antenna derived from spherical harmonic/Bessel function expansion of solution to Maxwell's equations
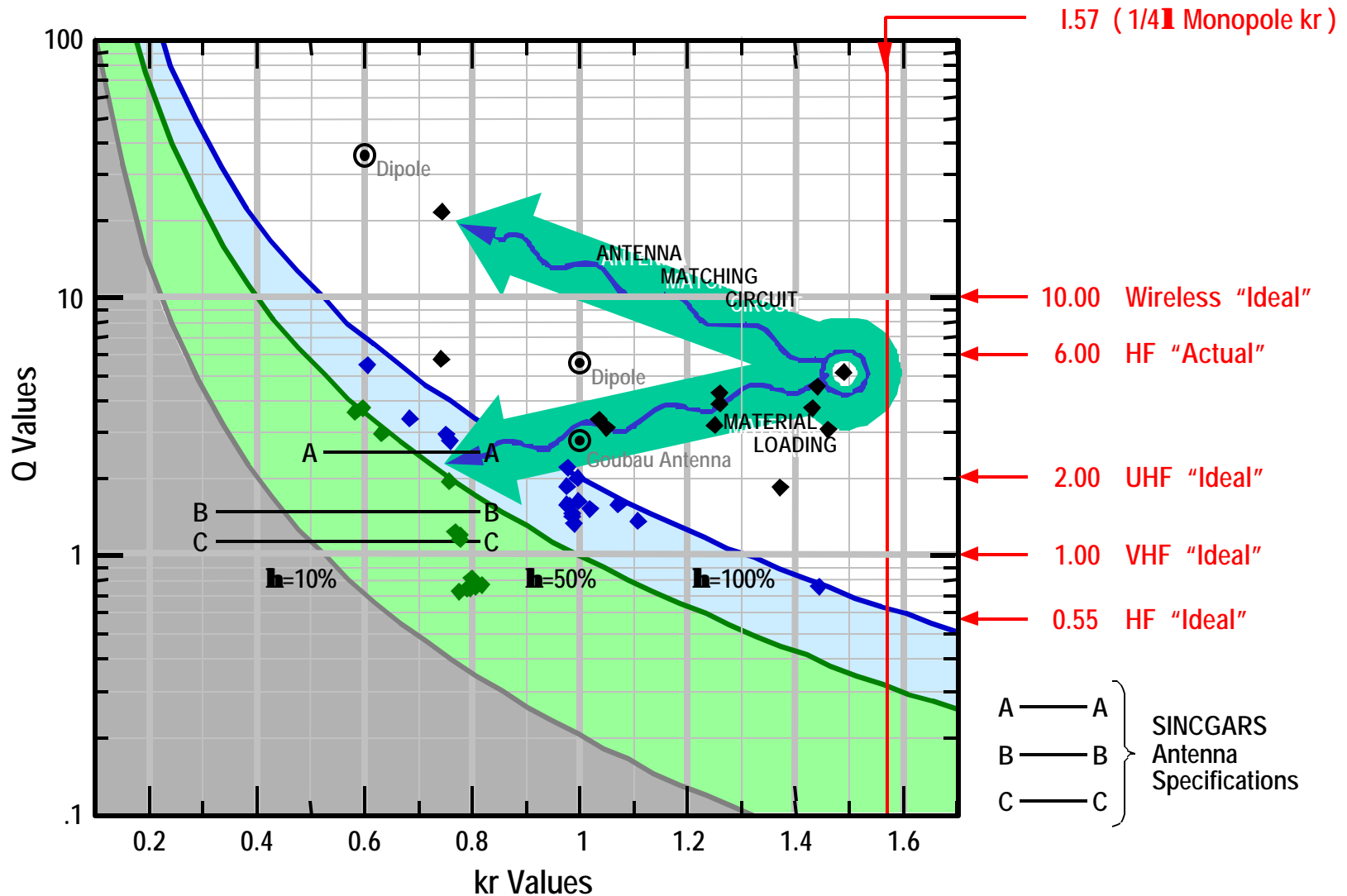
Antenna Loading Offers Small Wideband Antennas

Other Approaches

■ **Electronically Scanned Array Antennas**

- ‣ Patch Elements
- ‣ Wideband Elements
- ‣ T / R Units

■ **Wire Antennas**

- ‣ Dipole Elements in Arrays
- ‣ Spiral Elements and Arrays
- ‣ Log Periodic Arrays

Materials add additional degrees of design freedom
to both ESA and Wire antennas

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Why Is It Hard?

- **New Electromagnetic Materials**
  - Existing High ε Materials Too Heavy (~ 5– 6 grams / cm^3 vs . Potential ~1gm / cm^3)
  - Existing High μ Materials too Lossy
  - Limited Bandwidth for Negative Constituent Parameter Ranges
  - Must Ensure Sufficiently Large Breakdown Voltages (> 100 KV / cm)
  - Must Ensure Proper Material Properties in Useful Temperature Range
  - New Techniques for Fabrication of Materials

- **New Antenna Concepts**
  - Radiation Without Wires (Direct Radiation from Dielectric)
  - Overcome Material Impedance Mismatch for Antennas (Wide-Band, Geometrically Small)
  - Integration of Antenna and RF Stages

- **Material Exploitation**
    - Fabrication yield too low (Goal: yield comparable to I.C.s)
    - Temperature effects on properties (Goal: Curie Temperatures > 100 C)
    - Anisotropy or inhomogeneity in constituent parameters (Goal: exploit in designs)
    - Weight of material too high (Goal: specific gravity ~ 1)
- **Antennas**
    - RF coupling problems (Goal: > 90% of energy coupled near Brewster Angle)
    - VSWR, bandwidth, sensitivity, gain, loss (Goal: better than wire antennas)
    - Noise physics, breakdown voltages (Goal: Breakdown voltage > 100 KV/cm, system noise temperature ~ 300 K)
    - Size, weight, other mechanical properties (Goal: comparable to plastics)